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Biosafe sustainable antimicrobial encapsulation and coatings for targeted treatment and infections prevention: Preparation for another pandemic

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ABSTRACT

There has been a growing concern for safety and precautions in the wake of coronavirus SARS-CoV2 pandemic also dubbed as COVID-19, which has caused a major impact at a global scale. This has resulted in many industries accelerating at fast pace new biosafety technologies and improving the already existing ones to deal with this highly contagious virus. Most governments across the globe are also mandating policies focusing on increased biosafety to prevent further spread of the virus and protect key workers such as healthcare agents, store employees and police. The COVID-19 pandemic has exposed huge gaps in the healthcare industry that include lack of effective vaccines and medicines, testing of infection, real-time monitoring of the spread of the virus, inadequate protective equipment, and scarcity of protective and intensive care of patients. Some of these may be attributed to a lack of focused research in biosafety materials. As a consequence of the pandemic, a significant body of research activities has therefore focused on biosafety materials that possess unique properties needed for biosafety applications. This graphical review aims to provide a perspective on the usage of bio-based materials to handle the imposing challenges in biosafety. This review investigates existing developments in bio-based antimicrobial encapsulations as an effective measure to deter the growth of COVID-19 virus on surfaces and minimize its spread through surface contact. This will help researchers develop further strategies in material science to focus on contagious pathogens in the future.

1. Introduction

Advancements in the field of biotechnology and associated research on finding and developing new pathogens have exposed the gaps in biosafety measures and standards across the globe. This has resulted in the outbreak of infectious diseases globally, posing grave dangers to human society and the environment [1]. Be it the Spanish Flu, H1N1 Swine Flu, Ebola outbreak, the Zika virus or COVID-19, each pandemic has provided a setback to the global economy while severely impacting the society. Most outbreaks have been due to poor biosafety standards and delayed response from a biosafety standpoint to contain the spread. Given the unprecedented challenges posed by the COVID-19 epidemic, there is a resurgence of interest in the biosafety industry that can better prepare the world for similar situations in the future as well as contain the current pandemic. This entails a need to push forward the technologies and techniques in material science [2] which is an integral part of improving the biosafety standards and producing materials that can protect against these potentially deadly pathogens. The development of effective antiviral and antimicrobial coatings and treatments is particularly important in the transport industries like aerospace.

While there have been some commercially available materials that are effective against pathogens [3,4], the unknown nature of COVID-19 virus has resulted in a need to study the impact of other prospective biosafety materials candidates that could prove useful in remediating the

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virus and slowing down its spread. Many chemical surfactants and anti-microbial coatings can be used to eliminate the virus, but they pose the challenge of being non-degradable and potentially hazardous to the environment as well as humans [5] Traditionally these would include coatings containing zinc, copper, titanium, quaternary ammonium compounds and silver nanoparticles which get released into the environment [6]. Thus, they need to be replaced with green, biobased renewable materials that have a significantly lower ecological impact [7]. While chitosan has been a long-standing green biobased antimicrobial material [6], many other materials such as biobased polyurethane and Ag nanocomposite [8,9], chitosan bionanocomposites [10], Ag nanoparticles from orange waste [11], nanocellulose [12] have been proposed in the recent past in this regard.

These naturally derived green materials can be utilized as the first line of defence against the spread of COVID-19 by their application on common surfaces across home, offices, hospitals and airports. These antimicrobial materials are also important components of personal protective equipment (PPE) to protect frontline medical professionals and the general public. The current class of PPE have lower resistance and nearly zero antimicrobial properties making their usage less effective against novel viruses such as COVID-19. Thus, there is a need to utilize materials with wider antimicrobial properties to maximize their effectiveness in contaminated environments.

2. Antimicrobial materials for preventing COVID-19 growth

It has been found that the contamination of a push plate door entrance into an office building can lead to contamination of 50% of the commonly touched surfaces and hands of office workers within 4 h [13]. Microbial growth occurs in public places on the surfaces of common contact areas due to the formation of a biofilm which provides a feasible environment for bacteria to secrete extracellular polymeric substances resulting in the capture of enveloped viruses such as coronaviruses on the surface. COVID-19, being an enveloped virus, has four main structural proteins i.e. spike (S), envelope (E), membrane (M), and nucleocapsid (N) proteins (Fig. 1). The S-protein in COVID-19 attaches itself to various surfaces resulting in its transmission [14].

As reported by Ref. [15] COVID-19 virus can survive for up to 4 h on copper, several hours on aluminium, sterile sponges, or surgical gloves, up to 24 h on cardboard and 2–3 days on plastic and stainless-steel surface. Thus, it is imperative to prevent the spread of COVID-19 on these surfaces through antimicrobial encapsulation that will deter their capture and growth. Surfaces treated with antiviral encapsulations render the viruses non-infective on encountering the treated surface. Nanomaterials have been found to possess antimicrobial impact due to their unique

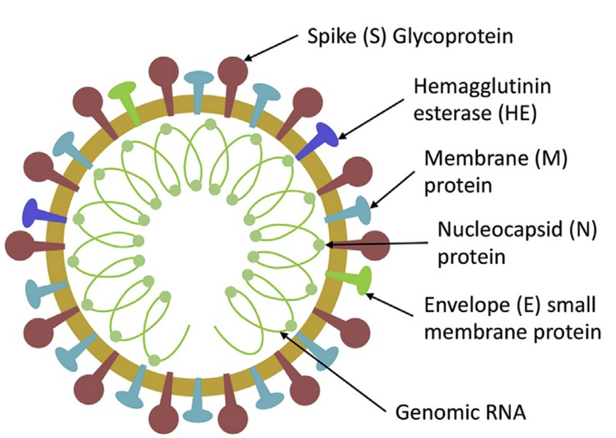

Fig. 1. The general structure of the COVID-19 virus which is spherical with club-shaped glycoprotein projections in the envelope. (Adapted and modified from Biowiki http://ruleof6ix.fieldofscience.com/2012/09/a-new-coronavirus-should-you-care.html).

chemical and physical characteristics and high surface-area-to-volume ratio. The nanoparticles facilitate presentation and stabilization of the antigens on administration and further serve as adjuvants for boosting the immune response. They act as carriers for target-based delivery of antigens against viruses. Metal nanoparticles can adhere to the viral envelope, the membrane of cells, and then enter the interior, destroying genetic materials such as DNA and RNA [16] (Fig. 2).

Ag nanoparticles (AgNP) have received special attention due to their applicability across multiple sectors as an antimicrobial protection layer in air filters, textiles, biomedical industry and food packaging [11]. used orange (*Citrus sinensis*) waste to extract AgNP which has been proven to be effective against microbes. AgNPs have further prevented the activity of viruses by eliminating aerosolised bacteriophage MS2 virus particles [17]. Invitro studies have observed that AgNPs can inactivate several types of viruses like monkeypox virus, Tacaribe virus, HIV-1, hepatitis B, Rift Valley fever virus, influenza viruses such as H1NI and H3N2 [18]. [19]; encapsulated natural curcumin in a novel polymeric micelle (PM) in presence of AgNP to enhance the antimicrobial activity of the material on *Pseudomonas aeruginosa* (*P. aeruginosa*) and *Staphylococcus aureus* (*S. aureus*) (Fig. 3).

Nanomaterials are also effective in reducing the *in vivo* replication of the viruses from various families. Although chitosan already possesses antimicrobial properties, bionanocomposites developed by combining chitosan with other nanomaterials have proven to have enhanced activity. E.g. silver-loaded ZnO nanoparticles, when added to chitosan/gelatin, exhibited higher antimicrobial activity on *E. coli* and *S. aureus* [10]. [20] presented the idea of incorporating positively charged chitosan nanofibers in the personal protective clothes/fabrics of the health care providers to hence enhance their protection, and safety. Companies such as Muse wearables (Consumex Industries, India), OrganoClick (Sweden), Ryan Nanomedicines (China) are already implementing biobased formulations into PPEs and other materials. Researchers at Jawaharlal Nehru Center for Advanced Scientific Research (JNCASR), and CIIRC-Jyothy Institute of Technology (India) have developed charge switchable polymeric coatings and polymer-based antimicrobial surface coating, respectively to protect against SARS-Cov2 virus [21]. demonstrated that polyphenol Catechin could be used to modify commercial cellulose fibres to produce antiviral masks. In another experiment [22]; we're able to enhance the antimicrobial efficacy and applicability of *Bombyx mori* silk (which is used as a biomaterial in surgical sutures) by loading AgNP in the silk fibres produced from aqueous extract of *Rhizophora apiculata* leaf. These AgNP loaded silk fibres were able to inhibit >90% *P. aeruginosa* and *S. aureus*. Biobased polyurethane derived from renewable materials like algae oil and ricinoleic acid silver doped chicken egg-shell nanoparticles (AgNP) was found to be an excellent antimicrobial surfactant against gram-negative and gram-positive bacteria such as *E. coli* and *S. aureus* [8]. Preliminary evaluations by Ref. [23] on a modified coating using quaternary ammonium coating are highly effective against human coronavirus (HCoV) 229E, with remediation rate of >90% in 10 min and by > 99.9% after 2 h contact. These natural antimicrobial materials can be effectively utilized as linings and treatment materials to produce a range of biosafety equipment such as air filters, PPE and surface coatings (Fig. 4). Air filters depend on dense fibrous materials to stop particulate matter but the addition of antimicrobial materials such as polyurethane coated with methanolic extract of *Euscaphis japonica* or AgNP or *Sericin* from *Bombyx mori* or *Grapefruit seed extract* (GSE) or ethanolic extract of *Sophora flavescens* has been proven to achieve filtration efficiency in the range of 95–99.99% for common pathogens [24].

3. Post-COVID 19 biomedical market trends

COVID-19 has resulted in a rising impact of getting microencapsulated materials especially into several industries like food and beverage, pharmaceutical, and agrochemical businesses. Technological advancement, as well as the demand in the global market due to COVID-

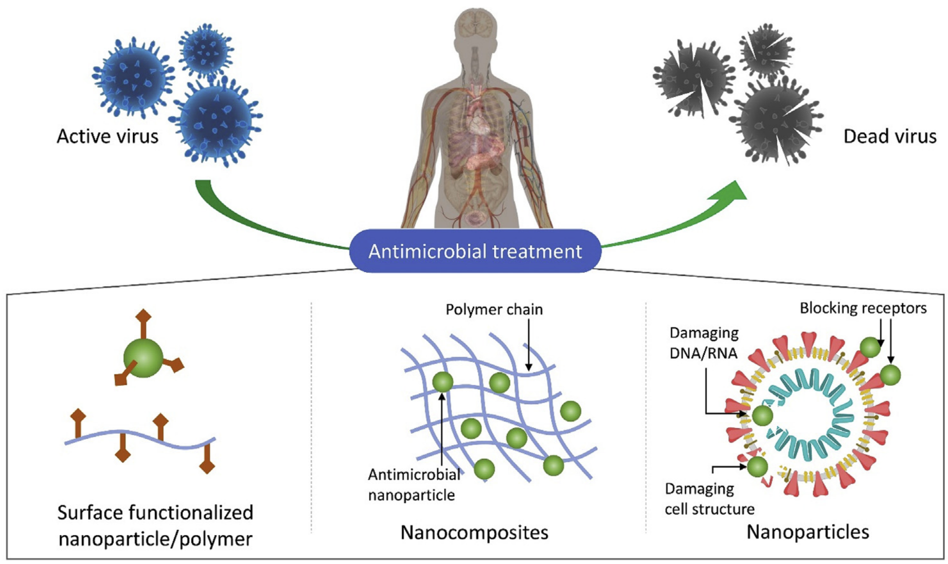

Fig. 2. Antimicrobial treatment for SARS-CoV2 virus involving nanomaterials can include the following strategies: 1. Surface functionalization of nanoparticles and polymeric chains with antiviral agents which can cause death of the virus upon contact e.g. quaternary ammonium compounds (QACs) 2. Fabrication of nanocomposite structure by filling the structure with Ag nanoparticles (AgNP) 3. Surface coating with nanoparticles which can prevent the spread of virus by blocking the receptors and forming physical barrier and preventing cell docking. AgNP can also cause viricide by damaging the DNA/RNA as well as the cell walls.

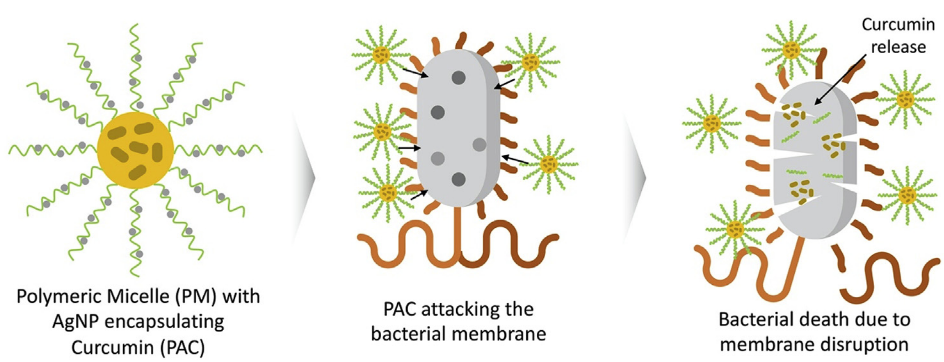

Fig. 3. The self-organizing biodegradable PM loaded with AgNP is used to encapsulate curcumin in its core. The embedded AgNP damages the bacterial shell while rapidly releasing the encapsulated curcumin which further accelerates the death of bacteria eventually resulting in bacterial film cleansing (Adapted and Modified), (Reprinted with the permission from Huang et al. copyright © 2017 American Chemical Society).

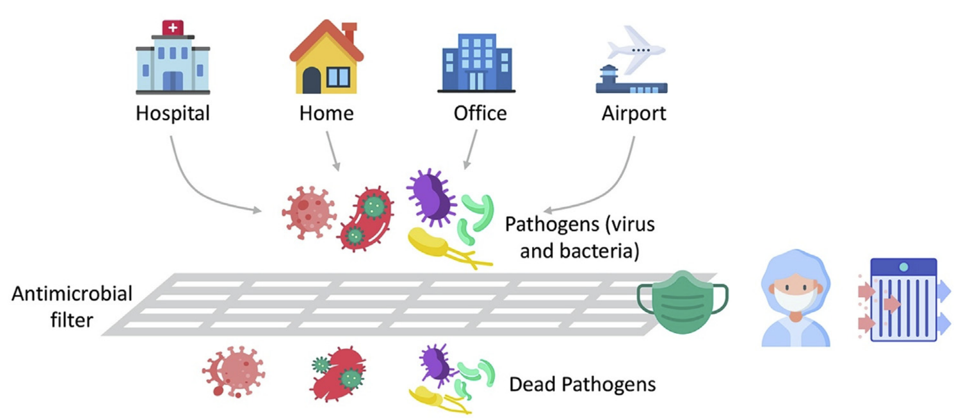

Fig. 4. Biosafety materials for PPE and filtration systems with antimicrobial capacity. Most of the pathogens are eliminated when they reach the antimicrobial filter layer.

19 impact, is anticipated to be a major aspect for the market growth. It is reported that several countries like US., U.K., Germany, France, China, India, Australia, South Korea, South Africa, etc., are expected growth of profits at global, regional, and country levels during 2019–2025 period (Fig. 5).

Microencapsulation method, which is mainly utilized for disguising taste, odor, and activities of the encapsulated structures, which in turn play the role as a useful ingredient to numerous applications of the pharmaceutical and healthcare sector. Sodium alginate, PVA, ethylcellulose, gelatin, and polysaccharides are among the ingredients used for microencapsulation technology [25,26,27]. The global trend has further witnessed a growing demand for the use of spray technology,

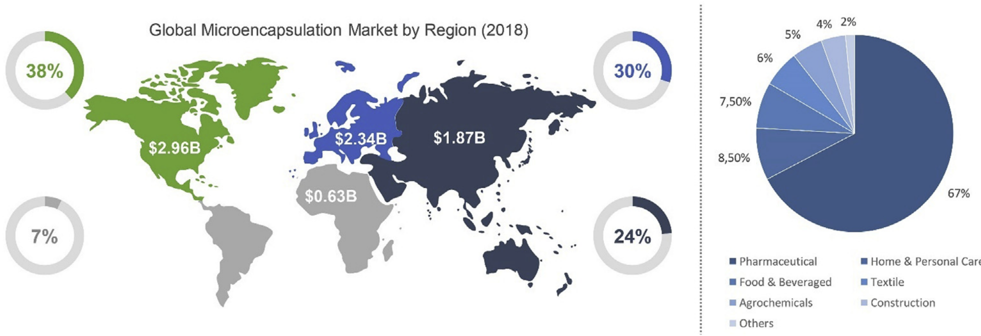

Fig. 5. Global microencapsulation market share, by application, 2018 (%) (Source: grandviewresearch.com).

methods to manufacture beauty enhancements, manufacture of cosmo-textiles, increasing consumption of n-3 fatty acids for health, changing pattern of consumer spending have contributed the expansion of microencapsulation market, predicting better market growth (Fig. 6).

The projected period from 2019 to 2025 is providing a predictable growth of Polymer as a coating material of CAGR of 14.2%. A growth of CAGR of 13.3% is expected for pan coating, fluidized bed coating, and air suspension coating. Though uncertainty regarding the availability of the raw materials, is highly anticipated, this sector is promising a stable growth. To tap the customer base, strategic partnership between the firms are highly envisaged, though it invites growing competition between the industry members.

4. Conclusion and outlook

A variety of biobased materials, such as polyurethane, naturally derived nanoparticles natural antimicrobial agents, are emerging as the source of biosafety materials, while reducing the impact on the environment due to their usage and disposal. Some examples of green sources of antiviral agents that could become prominent include chitosan enhanced with green seed extract and green tea extract, polyhydroxybutyrate in combination with Cinnamaldehyde, copper embedded polymeric fibres, carboxymethyl chitosan polymers, essential oils incorporated into capsules, coatings, or films and ethylcellulose with acetoxy-polydimethylsiloxane bonded with clove essential oil. In the post-COVID-19 era, it will be important to prioritize biosafety using these greener materials. Although recent years have witnessed significant progress in the development of biobased antimicrobial materials, efforts are still needed to make them mainstream and economically feasible to produce at a large scale. The development of biobased materials to deter the growth and spread of pathogens that spread at a high rate such as

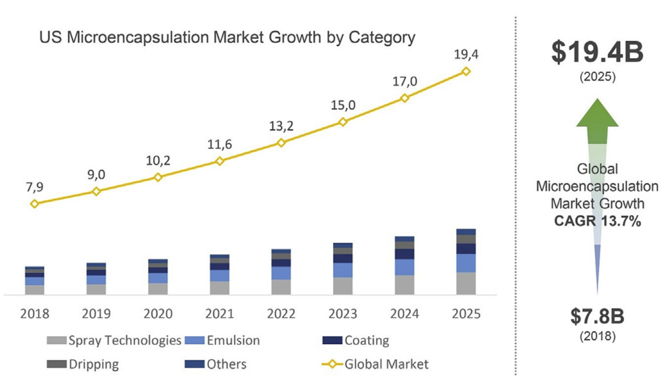

Fig. 6. U.S. microencapsulation market share, by category, 2014–2025. A market valuation of USD 7.88 billion is reported for global microencapsulation market size in 2018. Expected growth of CAGR of 13.7% is notified for a period up to 2025 (Source: grandviewresearch.com).

COVID-19 is needed. Globalization has made these biothreats and pandemics a problem for every country, and global collaboration and cooperation is needed to tackle future threats. Hence research efforts need to be brought together and dissemination of information across the scientific community is needed to accelerate the development of bio-based biosafety materials to secure the health and well-being of society and economic prosperity.

CRediT authorship contribution statement

Zeba Usmani: Conceptualization, Writing – original draft. **Tiit Lukk:** Writing – review & editing. **Dileep Kumar Mohanachandran:** Writing – review & editing. **Vijay Kumar Thakur:** Writing – review & editing. **Vijai Kumar Gupta:** Supervision, Writing – review & editing. **Dave Robert:** Writing – review & editing. **Jog Raj:** Writing – review & editing. **Fabrizio Scarpa:** Writing – review & editing. **Raju Kumar Gupta:** Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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